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FLUOROIODIDE BLENDS AS STREAMING AGENTS: SELECTION CRITERIA AND CUP-BURNER RESULTS

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Fluoroiodocarbons (FIC) -- highly effective, "second-generation" agents -- have been identified as replacements for halons, the production of which ended on 31 December 1993. In an attempt to improve the toxicological characteristics of FICs, to decrease agent cost, and to possibly improve performance as a streaming agent in military applications, blends of FICs with other chemicals are being investigated. This report describes the initial results of the blending work with trifluoroiodomethane (CF_3I), the most promising FIC fire suppressant. Toxicities, likely regulatory regulations, and availability indicate that only hydrofluorocarbons (HFC) can be considered at this time for blending with CF_3I or other FICs. Seven HFCs (HFC-236fa, -227ea, -143a, -134a, -125, -23, and -4-3-10mee) were selected for initial investigation. Based on the toxicities of CF_3I and the proposed blending agents, the final blends should contain 40 percent or less by volume CF_3I in order for the cardiac sensitization No Observed Adverse Effect Level (NOAEL) value to be equal to that of Halon 1211. Cup-burner extinguishment concentrations at a 40 percent by volume CF_3I concentration ranged from slightly higher to significantly lower than those for pure CF_3I. Those agents identified as meeting the criteria for continuation in the program should be tested in laboratory- and field-scale streaming apparatuses.

14. SUBJECT TERMS

Fluoroiodocarbons; FIC; Halon 1211; Halon replacement;
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LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AEL	Acceptable Exposure Limit
AFB	Air Force Base
ALC	Approximate Lethal Concentration
APT	Advanced Protection Technologies
ARA	Applied Research Associates
CAS	Chemical Abstract Services
CFC	chlorofluorocarbon
CGET	Center for Global Environmental Technologies
CNS	Central Nervous System
EPA	Environmental Protection Agency
FC	fluorocarbon (perfluorocarbon)
FIC	fluoroiodocarbon
FTIR	Fourier Transform Infrared
GWP	Global Warming Potential
HBFC	hydrobromofluorocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
IUPAC	International Union of Pure and Applied Chemistry
LOAEL	Lowest Observed Adverse Effect Level
NMERI	New Mexico Engineering Research Institute
NOAEL	No Observed Adverse Effect Level
ODP	Ozone Depletion Potential
PFC	perfluorocarbon
SNAP	Significant New Alternatives Policy
U.S.	United States
USAF	United States Air Force
VOC	Volatile Organic Compound

FOREWARD

A. OBJECTIVE

The objective of the overall advanced agent program is to develop new, highly effective chemicals to replace Halon 1211 in military streaming applications. The portion of the work discussed in this document has, as an objective, the development of fluoroiodocarbon (FIC) blends as Halon 1211 replacements for streaming agents. This report documents initial work in that area.

B. BACKGROUND

The production of halons, used for fire and explosion protection, ended on 31 December 1993 in developed nations. Among the candidates being developed to replace halons are the FICs, highly effective, "second-generation" agents. In an attempt to improve the toxicological characteristics of FICs, to decrease agent cost, and to possibly improve performance as a streaming agent, blends of FICs with other chemicals are being investigated under a much larger advanced streaming agent development program. This report describes the initial results of the blending work with trifluoroiodomethane (CF_3I), the most promising FIC fire suppressant.

C. SCOPE

Work to develop advanced halon replacements was initiated in September 1993 under the Advanced Streaming Agent Testing Program. The objective of this program, which is now being continued under the Advanced Agent Program, is to develop new advanced chemical replacements for Halon 1211 in streaming applications. Fluoroiodocarbon blends, the subject of this report, is one element of the Advanced Agent Program.

D. RESULTS

Consideration of toxicities, likely regulatory regulations, and availability indicated that only hydrofluorocarbons (HFC) can be considered for blending with CF_3I or other FICs (at the time that this study was performed). Forty-four (44) HFCs were selected from the CGET CHEMICAL OPTIONS Database to obtain an initial broad list of compounds. Two recently-announced HFCs were also added to the list. From this broad list, seven HFCs (HFC-236fa, -227ea, -143a, -134a, -125, -23, and -4-3-10mee) were selected for initial investigation. Based on the toxicities of CF_3I and the proposed blending agents, it is estimated that less than 40 percent by volume CF_3I must be contained in a mixture in order for the cardiac sensitization No Observed Adverse Effect Level (NOAEL) value for the blend to be equal to that of Halon 1211.

Cup-burner extinguishment concentrations were obtained for the pure agents and blends. Test descriptions and results are presented.

E. CONCLUSIONS

Seven HFC chemicals (HFC-236fa, -227ea, -143a, -134a, -125, -23, and -4-3-10mee) have been identified that meet toxicity, regulatory, and availability requirements for inclusions as blending agents with CF_3I. For the five agents with known cardiac sensitization NOAEL, no more than 40 percent CF_3I may be contained in a blend in order to have the same cardiac sensitization NOAEL as that of Halon 1211. Fire suppression effectiveness testing using the cup-burner method gave extinguishment concentrations for four blended agents containing 40 percent CF_3I; these concentrations ranged from slightly higher than that of pure CF_3I to significantly lower (for blends with HFC-227ea). The reason for unexpectedly low extinguishment concentrations for some blends cannot be explained at this time. Separation of the components in the test cylinder was indicated to be negligible through Fast Fourier Transform Infrared (FTIR) spectroscopy analysis at different times during agent discharge.

F. RECOMMENDATIONS

Those agents identified in this effort as meeting the requirements for blending with CF_3I should be tested in laboratory- and medium-scale apparatuses to determine their performance as a streaming agent. Cardiac sensitization NOAEL and Lowest Observed Adverse Effect Level (LOAEL) values should be obtained for CF_3I blends identified in this phase of the project.

PREFACE

This report was prepared by the Center for Global Environmental Technologies (CGET), New Mexico Engineering Research Institute (NMERI), The University of New Mexico, Albuquerque, New Mexico, for the Infrastructure Technology Section of Wright Laboratory (WL/FIVCF), Tyndall Air Force Base, Florida, and Applied Research Associates (ARA), Inc., Tyndall Air Force Base, Florida 32403-5323, under Contract S-5000.7, NMERI Number 8-31790. This document provides a review of fluoroiodocarbon blends as potential halon streaming agents.

The Start Date for the overall Advanced Streaming Agent Program was 27 September 1993, and the End Date was 31 December 1994. The program segment on fluoroiodocarbon blends, the subject of this report, was initiated in October 1994. The WL/FIVCF Project Officer was Charles J. Kibert, the ARA Project Officer was Michael A. Rochefort, and the NMERI Principal Investigator was Stephanie R. Skaggs.

SECTION I

INTRODUCTION

Halon production ceased at the end of December 1993. A number of candidate replacement agents have been announced by industry for commercialization, and additional chemicals are under consideration. Most of the announced agents are "first-generation" agents — hydrochlorofluorocarbons (HCFC), hydrofluorocarbons (HFC), perfluorocarbons (PFC or FC), and hydrobromofluorocarbons (HBFC). All of the first-generation candidates, however, have one or more drawbacks in terms of effectiveness, global environmental impact, or regulatory acceptance. Consequently, the search for candidates that are effective but have minimal global environmental impacts has continued.

"Second-generation" halon replacements are designed specifically to avoid the effectiveness and environmental tradeoffs of first-generation agents. Second-generation agents are highly effective fire extinguishants, but have zero or near-zero Ozone Depletion Potential (ODP) and Global Warming Potential (GWP). The most promising near-term second-generation candidate identified to date is trifluoroiodomethane (CF_3I).

Despite the promise of CF_3I as a halon replacement, a number of potentially show-stopping questions remained unanswered in early 1993. Thus, in May 1993, a coordinated ad hoc working group was formed to expedite the development of CF_3I. Members of the CF_3I Ad Hoc Working Group included representatives from the United States Air Force (USAF), U.S. Navy, U.S. Army, North Slope Halon Task Group, Pacific Scientific, and West Florida Ordnance. Over the next 18 months, studies were performed to address issues related to fire suppression and explosion prevention effectiveness, initial acute toxicology, global environmental impacts, manufacturability, chemical stability, and materials compatibility. Results and conclusions on the work accomplished by the CF_3I Ad Hoc Working Group are compiled in Reference 1.

Throughout the development of CF_3I, the candidate had been emphasized as a Halon 1301 replacement for total-flood applications, because the physical and chemical characteristics are more similar to those of Halon 1301 than to the characteristics of Halon 1211, which is used in streaming applications (Table 1). However, initial field-scale experiments with CF_3I at Tyndall Air Force Base revealed that the chemical also demonstrates superior firefighting capabilities in streaming scenarios. Consequently, CF_3I has received significant attention by the military and industry as a streaming agent candidate.

TABLE 1. PHYSICAL PROPERTIES OF HALON 1301, HALON 1211, AND CF_3I.[a]

Physical Property	Halon 1301	Halon 1211	CF_3I
CAS No.	75-63-8	353-59-3	2314-97-8
Molecular weight, g/mole	148.91	165.37	195.91
Physical state at 20 °C	Gas	Gas	Gas
Melting point, °C	-168	-160.5	-110 (est.)
Boiling point, °C	-57.75	-3.4	-22.5
Liquid density at 20-25 °C, g/mL	1.54	1.83	2.096
Vapor pressure, psia at 25 °C	234.8	40.0	78.4
Heat of vaporization, kJ/kg	118.8	132.6	112.3
Liquid heat capacity, J/kg	870	775	592 (est.)
Vapor heat capacity, J/kg	469	452	361.8
Critical pressure, psia	574.6	610.0	586 (est.)
Critical temperature, °C	67	153.8	122 (est.)
Critical density, g/mL	0.745	0.713	0.87 (est.)

[a]Values from the CGET CHEMICAL OPTIONS Database.

The toxicological properties of Halon 1211 and CF_3I are provided in Table 2. Cardiac sensitization is the toxicological property emphasized since it is believed to be the effect that occurs at the lowest concentration when animals or humans are exposed to halocarbons (Reference 2). Some feel that since the cardiac sensitization threshold for CF_3I is lower than that of Halon 1211, a sufficient safety margin would not be provided if CF_3I were to be considered as a streaming agent. This conservative view may not be appropriate since studies on firefighter

TABLE 2. TOXICOLOGICAL PROPERTIES OF HALON 1211 AND CF_3I.

Toxicity Parameter	Halon 1211	CF_3I
Lethal concentration LC_{50}, rat, 15-min	[a]20 %	[b]27.4 %
Acute exposure, rat	[c]5.8 %, 12 min: Slight muscle tremors	[d]12 %, 15 min: Salivation, audible breathing
Cardiac sensitization, dog, 5-min, epinephrine challenge	[e]NOAEL = 0.5 % LOAEL = 1.0 %	[f]NOAEL = 0.2 % LOAEL = 0.4 %

[a] Reference 3.

[b] Reference 4.

[c] Reference 5.

[d] Reference 6.

[e] Reference 5; criteria for cardiac sensitization was ventricular tachycardia or fibrillation. Ventricular ectopic beats were observed in dogs exposed at 5 %.

[f] Reference 7; criteria for cardiac sensitization was multifocal ventricular ectopic beats or fibrillation.

exposure have shown that personnel are unlikely to be exposed to concentrations greater than 1000 ppm (0.1 percent) for streaming agents with an effectiveness similar to that of Halon 1211. Nonetheless, an effort is underway to blend CF_3I (and possibly other fluoroidocarbons [FIC]) with low toxicity agents in an attempt to improve the toxicological characteristics.

The goal in searching for CF_3I blends is to find a blend or blends with acceptable fire extinguishing efficiency and one that also has cardiac sensitization No Observed Adverse Effect Levels (NOAEL) equal to or greater than Halon 1211 (0.5 percent). The strategy is to mix CF_3I with blending agents that have much higher cardiac sensitization NOAEL relative to CF_3I. In theory, a blend of CF_3I with a "non-toxic" blending agent would yield a mixture with a cardiac sensitization NOAEL greater than CF_3I itself (i.e., a higher concentration would be needed to elicit a cardiac sensitization response). A common method for predicting the toxicity of a mixture is adapted from the American Conference of Governmental Industrial Hygienists

(ACGIH) (Reference 8). According to this method, the toxicity index of a binary mixture is calculated according to Equation (1).

$$1/T = C_a/T_a + C_b/T_b \tag{1}$$

where T is the toxicity index of the blend; C_a and T_a are the concentration and toxicity index of component a; C_b and T_b are the concentration and toxicity index of component b, and

$$C_a + C_b = 1 \tag{2}$$

Evidence in other halocarbon blends, however, suggests that this relationship may not hold true in all cases. Predicting the cardiac sensitization NOAEL of a mixture from the cardiac sensitization NOAEL values for the individual blend components has not always proven a reliable indicator for other halocarbon blends. For example, the predicted and measured cardiac sensitization NOAEL values for three halocarbon blends are listed in Table 3. One can see that the correlation between the predicted and measured NOAEL values is not good, at least in the case of HCFC Blend A.

TABLE 3. CARDIAC SENSITIZATION PREDICTIONS AND MEASUREMENTS FOR HALOCARBON BLENDS.

Halocarbon Blend		Predicted Cardiac Sensitization NOAEL, %	Measured Cardiac Sensitization NOAEL, %
HCFC Blend A	82 % HCFC-22 9.5 % HCFC-124 4.75 % HCFC-123 3.75 % limonene	2.1	[a]10
23/125	36.5 % HFC 23 63.5 % HFC 125	11	[b]< 10
R-502	51 % CFC-115 49 % HCFC-22	4.4	[c]5

[a] Reference 9.

[b] Reference 10; 10 % was the only concentration tested. One dog experienced ventricular fibrillation and death at 10%.

[c] Reference 11.

SECTION II

RATIONALE

Blending agents for use in USAF streaming applications must meet the criteria shown in Table 4, which are listed approximately in the order of importance. Note that fewer criteria are needed for a blending agent than for an active firefighting component. In particular, although fire extinguishing ability is not a major factor, toxicity is considered critical.

TABLE 4. CRITERIA FOR BLENDING CHEMICAL.

Property	Criteria
Toxicity	A blending agent must have a very low toxicity if the final blend is to have toxicity characteristics similar to those of Halon 1211. In particular, significant toxicological studies must have been performed, must be underway, or must be planned.
Environmental	A blending agent candidate must not now be regulated nor should it be regulated in the “near” future. The Ozone Depletion Potential (ODP) must be essentially zero.
Availability	Any material must be available in sufficient bulk for testing and manufacture must, at least, be planned.
Flammability	The material must have a very low flammability; however, marginally flammable materials might be acceptable as blending agents.
Boiling Point	The boiling point must be sufficiently high to allow use of the blending chemical without extensive equipment modification.
Materials Compatibility	The blending agent must be compatible with fire extinguisher components and with other materials with which it comes into contact.

Taking the above variables and the present state of knowledge into account, halocarbons are the most likely blending agents. There are now few, if any, other types of available blending materials that have the potential of being low in both flammability and toxicity, and have the required availability. Each type of halocarbon is discussed below.

A. HIGHLY REGULATED COMPOUNDS

Chlorofluorocarbons (CFC), hydrobromofluorocarbons (HBFC), carbon tetrachloride, and methyl chloroform can be eliminated from consideration since these chemicals are now or soon will be banned. Carbon tetrachloride cannot be used for other reasons as well.

B. HALOCARBON FAMILIES WITH SUSPECT TOXICITIES

Based on known toxicities of FICs, it is obvious that they should not be used to decrease the toxicity of blends containing other FICs. Alkenes are also unlikely to have a sufficiently low toxicity to meet the blending agent requirements. Nonfluorinated chlorocarbons and bromocarbons are often toxic and, in some cases, are regulated. Thus iodides, alkenes, and nonfluorinated chlorocarbons and bromocarbons are not recommended for blending.

C. HYDROCHLOROFLUOROCARBONS

HCFCs have exceptionally good properties for use as blending agents. A large number of these agents are known, the toxicities are often relatively low, and they are likely to blend well with iodides. However, HCFCs will be phased out of production in the future due to their non-zero Ozone Depletion Potential (ODP). Therefore, HCFCs are not recommended as blending agents.

D. PERFLUOROCARBONS

PFCs are fully fluorinated compounds (unlike CFCs, HCFCs, or HFCs) and have several attractive features. They are nonflammable, have very low toxicity, are exempt from federal Volatile Organic Compound (VOC) regulations, and do not contribute to stratospheric ozone depletion. However, under the Significant New Alternatives Policy (SNAP) program, the Environmental Protection Agency (EPA) has applied caution to the use of PFCs. The environmental characteristics of concern are their high GWP (approximately 5000 times that of carbon dioxide) and their long atmospheric lifetimes (about 3000 years). Although the actual contributions to global warming depend upon the quantities emitted, the long lifetimes make the warming effects of PFCs virtually irreversible. EPA allows the use of PFCs in fire extinguishants only for special applications where no other substitute would meet performance or safety requirements. Consequently, PFCs are not recommended for blending.

E. HYDROFLUOROCARBONS

HFCs are receiving increased prominence as replacements for ozone-depleting substances for three reasons: (1) they are usually volatile and many have low toxicities; (2) because they are not ozone depleting (as apposed to the HCFCs) and, because they have lower atmospheric lifetimes than PFCs, they are likely to receive less regulatory action than HCFCs or PFCs; and (3) they have properties similar to those of halocarbons that have been used in the past. This does not, however, mean that HFCs are not receiving attention from environmental organizations. A recent study by the National Institute of Public Health and Environmental Protection, The Netherlands, has projected a significant increase in greenhouse gas emissions as a result of the use of HFCs to replace CFCs and HCFCs (Reference 12). Moreover, the 1994 report of the UNEP (United Nations Environment Programme) Halon Technical Options Committee (HTOC) states that "...several governments have already restricted or banned the use of HFCs and PFCs" (Reference 13). Nevertheless, HFCs are the most promising halocarbons for use as blending agents with FICs.

SECTION III

PRELIMINARY SELECTION OF BLENDING AGENTS

A. RATIONALE

Consideration of toxicities, likely regulatory restrictions, and availability indicates that, at this time, only HFCs can be considered for blending with CF_3I or other FICs. HCFCs are being restricted in Europe, particularly for fire protection, and this greatly decreases their applicability in operations that could require application in overseas operations. Moreover, limitations on HCFCs are likely to spread to the U.S. (in fact, regulations against HCFCs in fire extinguishers for domestic use are already in place). Restrictions on PFCs are rapidly increasing in the U.S.

B. INITIAL SELECTION OF HYDROFLUOROCARBONS

The CGET CHEMICAL OPTIONS Database of 907 compounds was used to select an initial broad list of 44 HFCs (Table 5).

C. ADDITIONAL COMMERCIALLY AVAILABLE PRODUCTS

1. Hydrofluoroethers

Recently, three new fluorinated materials were announced without details on the specific compounds (Reference 14). The compositions of two of these materials have now been released and the properties are given in Table 6 (Reference 15). The composition of a third material, Liquid C, has not been reported. The reported chemicals, which are the partially fluorinated ethers methyl perfluorobutyl ether ($C_4F_9OCH_3$) and ethyl perfluorobutyl ether ($C_4F_9OC_2H_5$), appear to be exceptionally attractive. With a zero ODP and a lifetime lower than that of either the HFCs or the PFCs, they are unlikely to suffer from regulatory restrictions. Additionally, they are not VOCs and the toxicity appears to be very low. Because the formulations of these compounds were released after the work on this project was completed, it was not possible to include an assessment in this initial work; however, hydrofluoroethers appear to be very attractive as blending agents and should be considered for use in the future.

TABLE 5. ALL HYDROFLUOROCARBONS IN CGET CHEMICAL OPTIONS DATABASE.

Halocarbon No.	Formula	IUPAC Name	CAS No.	BP,°C
HFC-C354	$-CF_2CF_2CH_2CH_2-$	1,1,2,2-Tetrafluorocyclobutane	374-12-9	50
HFC-C234	-CF2CF2CH2-	1,1,2,2-Tetrafluorocyclopropane	3899-71-6	--
HFC-392	$CH_3CF_2CH_2CH_3$	2,2-Difluorobutane	353-81-1	31
HFC-374	$CH_3CF_2CF_2CH_3$	2,2,3,3-Tetrafluorobutane	471-74-9	17
HFC-365	$CF_3CH_2CF_2CH_3$	1,1,1,3,3-Pentafluorobutane	406-58-6	--
HFC-281ea	CH_3CHFCH_3	2-Fluoropropane	420-26-8	-9.39
HFC-281fa	$CH_3CH_2CH_2F$	1-Fluoropropane	460-13-9	-2.5
HFC-272ca	$CH_3CF_2CH_3$	2,2-Difluoropropane	420-45-1	-0.1
HFC-272fb	$CHF_2CH_2CH_3$	1,1-Difluoropropane	430-61-5	8
HFC-272fa	$CH_2FCH_2CH_2F$	1,3-Difluoropropane	462-39-5	41.6
HFC-272ea	$CH_2FCHFCH_3$	1,2-Difluoropropane	62126-90-3	--
HFC-263fa	$CHF_2CH_2CH_2F$	1,1,3-Trifluoropropane	24270-67-5	--
HFC-263fb	$CH_3CH_2CF_3$	1,1,1-Trifluoropropane	421-07-8	18
HFC-263eb	CHF_2CHFCH_3	1,1,2-Trifluoropropane	66794-35-2	--
HFC-263ea	$CH_2FCHFCH_2F$	1,2,3-Trifluoropropane	66794-36-3	--
HFC-263ca	$CH_2FCF_2CH_3$	1,2,2-Trifluoropropane	811-94-9	--
HFC-254ea	CHF_2CHFCH_2F	1,1,2,3-Tetrafluoropropane	24270-68-6	--
HFC-254cb	$CHF_2CF_2CH_3$	1,1,2,2-Tetrafluoropropane	40723-63-5	--
HFC-254eb	CF_3CHFCH_3	1,1,1,2-Tetrafluoropropane	421-48-7	--
HFC-254fb	$CH_2FCH_2CF_3$	1,1,1,3-Tetrafluoropropane	460-36-6	29.4
HFC-254fa	$CHF_2CH_2CHF_2$	1,1,3,3-Tetrafluoropropane	66794-30-7	--
HFC-254ca	$CH_2FCF_2CH_2F$	1,2,2,3-Tetrafluoropropane	813-75-2	--
HFC-245cb	$CF_3CF_2CH_3$	1,1,1,2,2-Pentafluoropropane	1814-88-6	-17.72
HFC-245ea	$CHF_2CHFCHF_2$	1,1,2,3,3-Pentafluoropropane	24270-66-4	--
HFC-245eb	CF_3CHFCH_2F	1,1,1,2,3-Pentafluoropropane	431-31-2	--
HFC-245fa	$CF_3CH_2CF_2H$	1,1,1,3,3-Pentafluoropropane	460-73-1	14
HFC-245ca	$CHF_2CF_2CH_2F$	1,1,2,2,3-Pentafluoropropane	679-86-7	--
HFC-236ea	$CF_3CHFCHF_2$	1,1,1,2,3,3-Hexafluoropropane	431-63-0	6
HFC-236cb	$CH_2FCF_2CF_3$	1,1,1,2,2,3-Hexafluoropropane	677-56-5	1.2
HFC-236ca	$CHF_2CF_2CHF_2$	1,1,2,2,3,3-Hexafluoropropane	680-00-2	10

TABLE 5. ALL HYDROFLUOROCARBONS IN CGET CHEMICAL OPTIONS DATABASE (CONCLUDED).

Halocarbon No.	Formula	IUPAC Name	CAS No.	BP, °C
HFC-236fa	$CF_3CH_2CF_3$	1,1,1,3,3,3-Hexafluoropropane	690-39-1	-1.5
HFC-227ca	CHF2CF2CF3	1,1,1,2,2,3,3-Heptafluoropropane	2252-84-8	-17
HFC-227ea	CF_3CHFCF_3	1,1,1,2,3,3,3-Heptafluoropropane	431-89-0	19
HFC-161	CH_3CH_2F	Fluoroethane	353-36-6	-37.7
HFC-152	CH_2FCH_2F	1,2-Difluoroethane	624-72-6	30.67
HFC-152a	CH_3CHF_2	1,1-Difluoroethane	75-37-6	-24.7
HFC-143a	CH_3CF_3	1,1,1-Trifluoroethane	420-46-2	-47.61
HFC-143	CH_2FCHF_2	1,1,2-Trifluoroethane	430-66-0	5
HFC-134	CHF_2CHF_2	1,1,2,2-Tetrafluoroethane	359-35-3	-19.72
HFC-134a	CH_2FCF_3	1,1,1,2-Tetrafluoroethane	811-97-2	-26.5
HFC-125	CHF_2CF_3	Pentafluoroethane	354-33-6	-48.5
HFC-41	CH_3F	Fluoromethane	593-53-3	-78.41
HFC-32	CH_2F_2	Difluoromethane	75-10-5	-51.6
HFC-23	CHF_3	Trifluoromethane	75-46-7	-82.03

TABLE 6. COMMERCIALIZED HYDROFLUOROETHERS.

Property	$C_4F_9OCH_3$	$C_4F_9OC_2H_5$
Boiling point, °C	60	73
Melting point, °C	-135	-117
Flash point, °C	None	None
Flammability limits	None	None
Solubility of water at 25°C, ppm	95	92
Solubility in water at 25°C, ppm	<10	<10
Liquid density at 23°C, g/mL	1.50	1.43
Viscosity at 23°C, cp	0.4	0.4
Surface tension at 23°C, dynes/cm	13.6	13.6
Heat of vaporization, 23°C, cal/g	30	30
Specific heat, cal/g °C	0.28	0.29
Atmospheric lifetime, years	5.5	1.2
ALC	>10%	>5%

2. HFC-4-3-10mee

HFC-4-3-10mee (1,1,1,2,2,3,4,5,5,5-decafluoropentane, $CF_3CHFCHFCF_2CF_3$, named as HFC-43-10mee by the manufacturer) is a recent product announced by DuPont (Reference 16). The partially fluorinated pentane has a boiling point of 54 °C. The Approximate Lethal Concentration (ALC) is 10,000 ppm; the Acceptable Exposure Limit (AEL) (which is being reviewed) is 400 ppm. Other toxicity parameters look good. In particular, both the Ames and the rat micronucleus tests are negative. Although the compound is reported to have no cardiac sensitization, the limit of the cardiac sensitization testing has not been reported. The compound shows no eye or skin irritation, but does exhibit some Central Nervous System (CNS) effects.

3. HFC-356mcf

HFC-356mcf (1,1,1,2,2,4-hexafluorobutane, $CF_3CF_2CH_2CH_2F$) is a partially fluorinated butane manufactured by AlliedSignal. Although HFC-356mcf was first announced as a product on 24 October 1994, considerable information is available (Reference 17). The HFC will be commercialized in 1996. As a whole, the toxicity looks promising. Neither adverse reaction nor irritation has been found in acute dermal testing, and no cardiac sensitization has been observed at 2 percent. One potential problem rests with the human lymphocyte studies, which show positive activity but only at very high concentrations. This potential problem is expected to be resolved in a subchronic study. As this report was being written, AlliedSignal announced a suspension of the development of HFC-356mcf, at least for cleaning applications (Reference 18).

D. DOWNSELECTION OF HYDROFLUOROCARBONS

Any option to halons must be approved under the EPA's SNAP program, which implements Section 612 of the amended Clean Air Act of 1990. The plan for the SNAP program and an initial list of decisions on acceptable and unacceptable halon substitutes were promulgated on 18 March 1994 (Reference 19). This plan was prepared from an EPA background document for halon replacements and alternatives (Reference 20). Additional lists or proposed lists of acceptability decisions have been published (References 21-25). Substances prohibited, acceptable only under certain conditions or for certain uses, or removed from a list of prohibited or acceptable substitutes are subject to public comment. Other substances for which there are no limitations are listed as acceptable with no public comment required. SNAP approval is required not only for pure materials but also for blends (and, by default, blend components).

Based on available toxicity information (or the promise that toxicity information will soon be available), on physical properties, and on availability, the chemicals in Table 7 were selected for initial investigations. This list contains one chemical, HFC-4-3-10mee, which was not in the initial broad list, but which was added later following announcement by the manufacturer. The SNAP assessment documents cited above were carefully reviewed to obtain regulatory environmental and toxicological assessments during this process. This list will likely change as further information is collected and reviewed. In addition, several of these materials, such as HFC-23, are likely to be too gaseous as blending chemicals for streaming agents and have not been emphasized as primary blend components.

E. TOXICITY ASSESSMENT

Table 8 presents the cardiac sensitization NOAEL values for the initial downselection list of chemicals in Table 7. Based on the method described earlier for predicting toxicity of mixtures, Equations (1) and (2) were used to estimate the HFC volume percentage needed to yielded a CF_3I mixture having a cardiac sensitization NOAEL equal to that of Halon 1211 (0.5 percent). The proportion of HFC for the mixture is listed in Table 9. As seen in this table, even for HFC-23, which has the highest cardiac sensitization NOAEL of all the blending agents, less than 40 mole percent CF_3I can be contained in a mixture in order for the estimated cardiac sensitization value for the blend to be equal to that of Halon 1211. Accordingly, future testing should focus on blends that have less than 40 percent CF_3I.

TABLE 7. INITIAL DOWNSELECTION LIST.

Halocarbon No.	Formula	IUPAC Name	CAS No.	BP, °C
HFC-236fa	$CF_3CH_2CF_3$	1,1,1,3,3,3-Hexafluoropropane	690-39-1	-1.5
HFC-227ea	$CF3CHFCF_3$	1,1,1,2,3,3,3-Heptafluoropropane	431-89-0	19
HFC-143a	CH_3CF_3	1,1,1-Trifluoroethane	420-46-2	-47.61
HFC-134a	CH_2FCF_3	1,1,1,2-Tetrafluoroethane	811-97-2	-26.5
HFC-125	CHF_2CF_3	Pentafluoroethane	354-33-6	-48.5
HFC-23	CHF_3	Trifluoromethane	75-46-7	-82.03
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1,1,1,2,2,3,4,5,5,5-Decafluoropentane	142347-08-8	54

TABLE 8. CARDIAC SENSITIZATION VALUES FOR INITIAL DOWNSELECTION LIST.

Halocarbon No.	Formula	Cardiac Sensitization NOAEL, %	Cardiac Sensitization LOAEL, %
HFC-23	CHF_3	[a]50	[a]>50
HFC-236fa	$CF_3CH_2CF_3$	[b]10	[b]15
HFC-227ea	CF_3CHFCF_3	9	10.5
HFC-125	CHF_2CF_3	[a]7.5	[a]10
HFC-134a	CH_2FCF_3	[c]4	[c]8
HFC-143a	CH_3CF_3	[d]4	[d]8
HFC-4-3-10mee	$CF_3CHFCHFCF_2CF_3$	Unknown	Unknown

[a] Reference 9

[b] Reference 26

[c] Reference 20

[d] Reference 19

TABLE 9. PROPORTION OF BLENDING AGENTS FOR CF_3I MIXTURES.

Blending Agent	Blending Agent Cardiac NOAEL, %	Minimum Percentage of Blending Agent[a]	Maximum Percentage CF_3I, vol %[a]
HFC-23	50	60.2	39.8
HFC-236fa	10	61.2	38.8
HFC-227ea	9	61.4	38.6
HFC-125	7.5	61.6	38.4
HFC-134a	4	63.2	36.8
HFC-143a	4	63.2	36.8

[a] Limiting amounts to obtain a NOAEL equal to or greater than that of Halon 1301 (0.5%).

SECTION IV

CUP-BURNER EXTINGUISHMENT CONCENTRATIONS

A. CUP-BURNER TEST METHOD

One of the most widely used apparatuses for determining the fire extinguishment concentration of Halon 1301 and 1211 replacements is the cup burner. Originally developed by Imperial Chemical Industries (ICI) in 1970 and refined in 1973, the cup burner is the standard flame extinguishment test technique accepted by the NFPA. The cup-burner apparatus was developed to measure the vapor phase performance of a chemical as a fire suppressant. Volumetric air and agent flow rates are used to calculate the molar percent concentration of agent required for flame extinguishment. Different techniques and equipment setups are required for testing gaseous, liquid, and "highly-volatile" liquid agents (Reference 27).* The cup-burner apparatus consists of a glass chimney containing a small glass flame cup filled with a liquid fuel or containing a central burner for a gaseous fuel. Measured amounts of extinguishing agent and air enter the bottom of the chimney, are mixed, and allowed to pass by the ignited fuel. The amount of extinguishing agent is increased until the flame is extinguished, and the percent (molar, gas volume) concentration of agent is calculated. This calculated value is called the cup-burner extinguishment concentration.

1. Gaseous Agent Cup-Burner Test Method

Under previous USAF contracts, NMERI developed and refined a reduced-scale cup burner and several test methods. A different test method is used depending upon the characteristics of the agent being tested. The classical gaseous agent cup-burner test setup monitors the gaseous flow rate of the agent, or agents when testing blends, using a flow rotameter and a soap film bubble meter (Figure 1). The agents are blended in the gas phase in the cup-burner mixing chamber. The classical method was one method used to determine the cup-burner extinguishment concentrations of HFC-125, -134a, -227ea, and -236fa blended with CF_3I.

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* Moore, J. P., Moore, T. A., Salgado, D. P., and Tapscott, R. E., "Halon Alternatives Extinguishment Testing," International Conference on CFC and Halon Alternatives, Washington, DC, October 10-11, 1989.

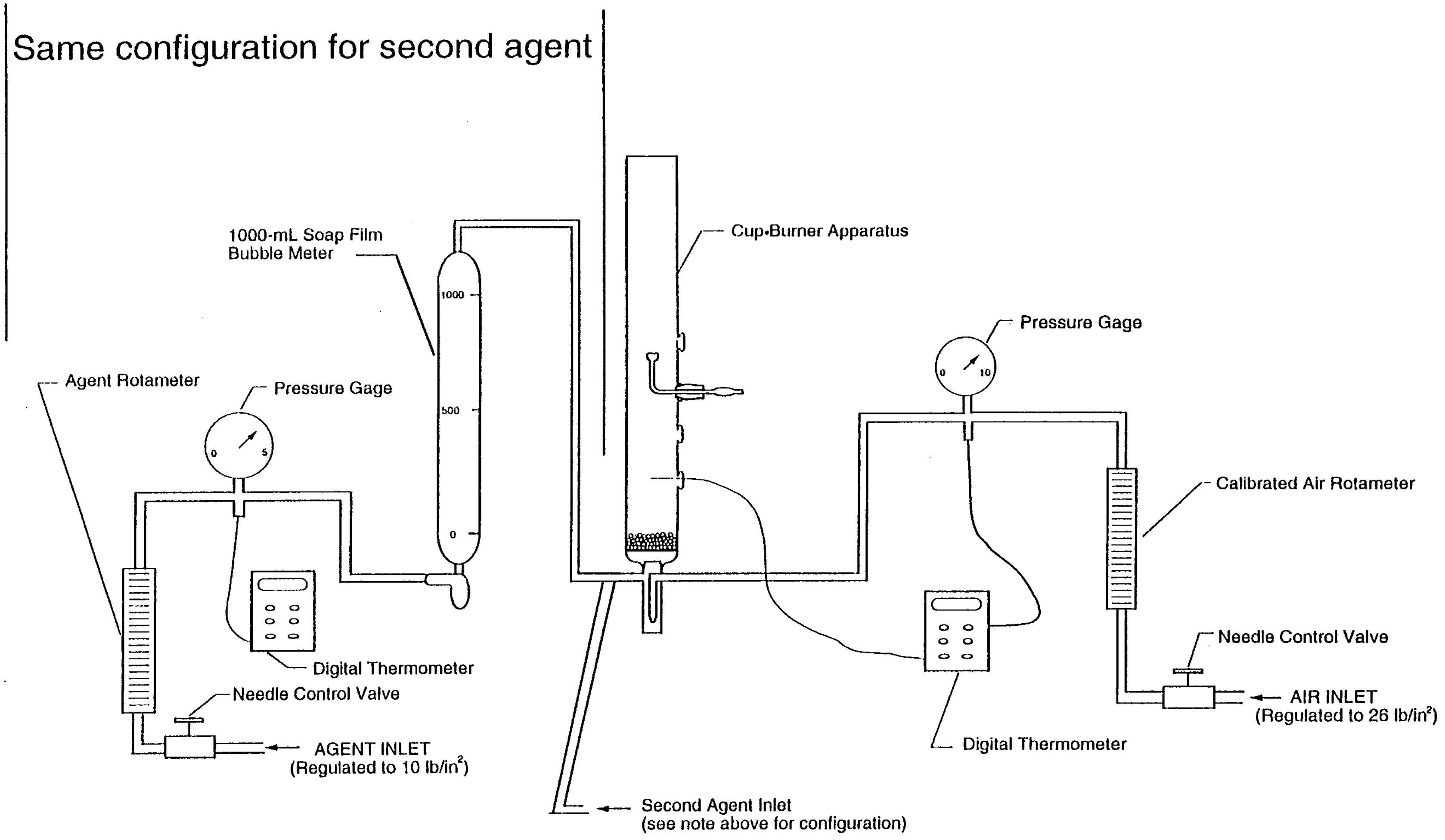

Figure 1. Classical Cup-Burner Apparatus Configuration for Testing Gaseous Agents.

2. Liquid Agent-Cylinder (Discharge) Cup-Burner Test Method

Recently, a unique test method was developed based upon a discharge cylinder, needle value, and electronic scale with computer data acquisition (Figure 2). Liquid compounds and those with boiling points near room temperature are usually tested using this liquid agent-cylinder (discharge) cup-burner method. The average results from five tests are used to determine the extinguishing concentration of the compound being tested. This method was also used to develop extinguishment concentrations for the CF_3I and HFC blends. In this method the CF_3I and the particular HFC compound were mixed in the discharge cylinder at various (pre-determined) weight percentages. Testing was then performed to determine the volume percent extinguishment concentration of the blend.

B. CUP-BURNER TEST RESULTS

Several blends of CF_3I and HFCs were tested using the NMERI 5/8-scale cup-burner test methods. The liquid agent-cylinder (discharge) method (Figure 2) and the gaseous agent method (Figure 1) were both used. Cup-burner tests were also performed at the Infrastructure Technology Section of Tyndall AFB, Florida, by Applied Research Associates, Inc., personnel, using their gaseous agent method. These unpublished Tyndall ARA data were originally based upon a volume percent blend ratio; however, for the discussion in this section, the ARA data were converted to a weight percent blend ratio. Over 200 cup-burner tests were performed with various blends of CF_3I and HFC-125, -134a, -227ea, and -236fa. The NMERI cup-burner test results for the CF_3I blends are shown in Tables 10 through 13.

Figure 3 and Table 10 show the cup-burner results for CF_3I blended with HFC-125 using the revised cup-burner test setup. The test data indicate that with 40 percent by weight CF_3I and greater in the blend, only a slight decrease in extinguishment performance from that of pure CF_3I would be experienced.

Figure 4 and Table 11 show the cup-burner results for CF_3I blended with HFC-134a using the discharge cup-burner test setup. An exponential curve fit to the Tyndall ARA data is also shown. The difference between the Tyndall ARA and the NMERI results is discussed further on in this section.

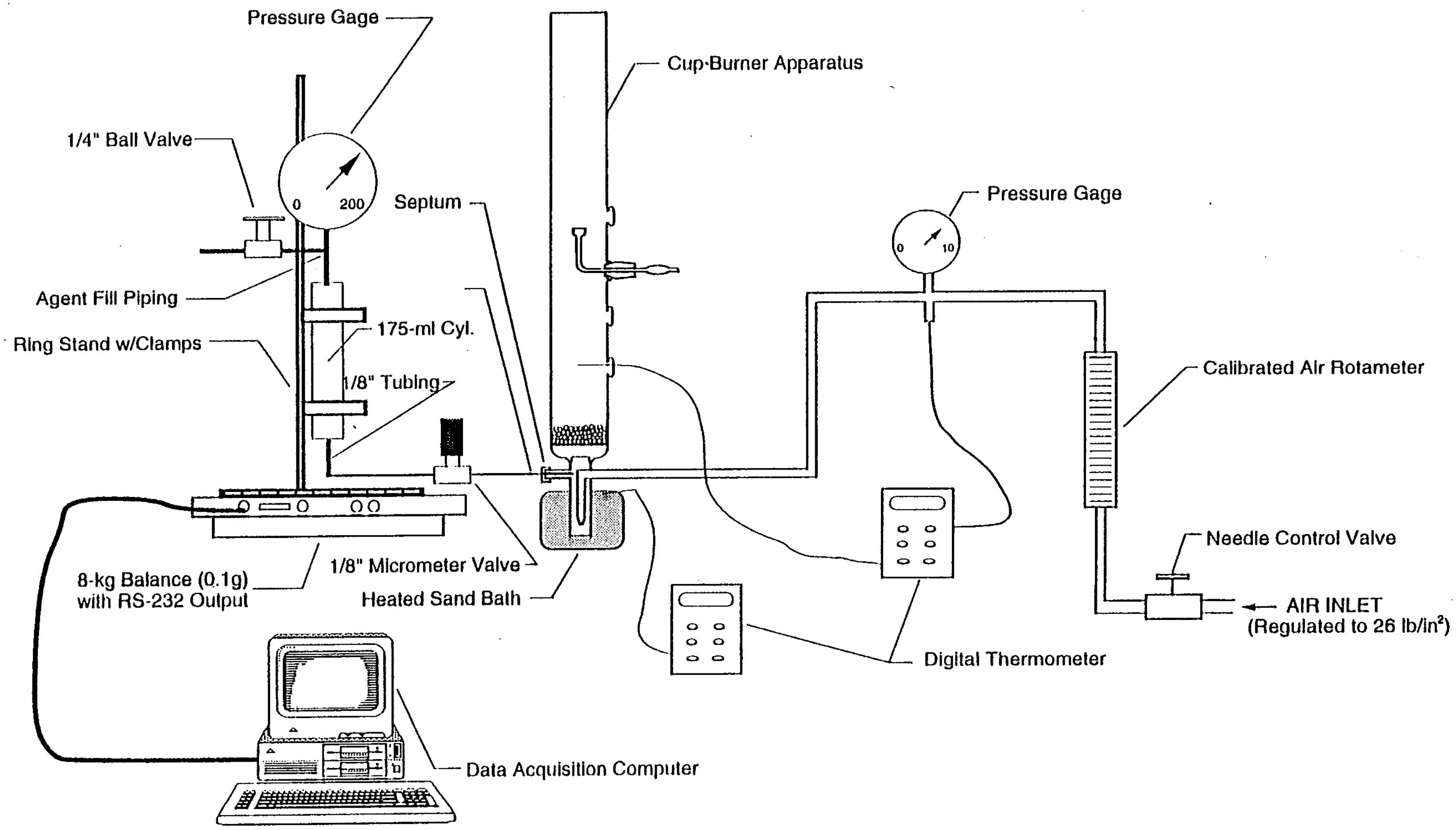

Figure 2. Revised Cup-Burner Apparatus Configuration for Testing Blends.

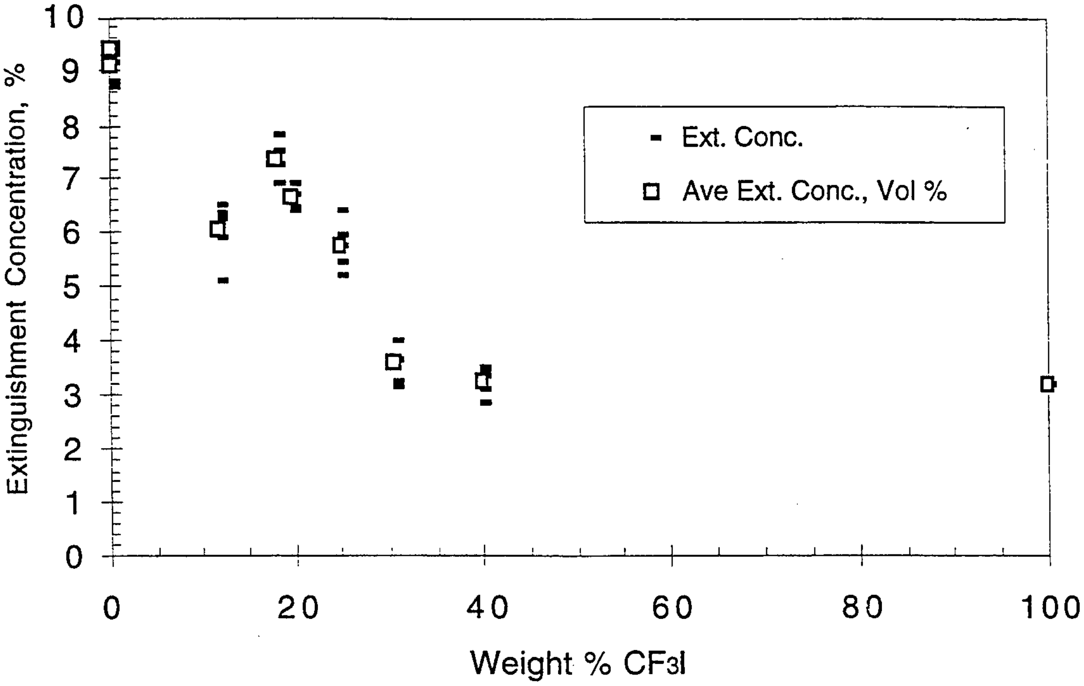

Figure 3. Cup-Burner Extinguishment Concentrations for CF_3I and HFC-125 Blends.

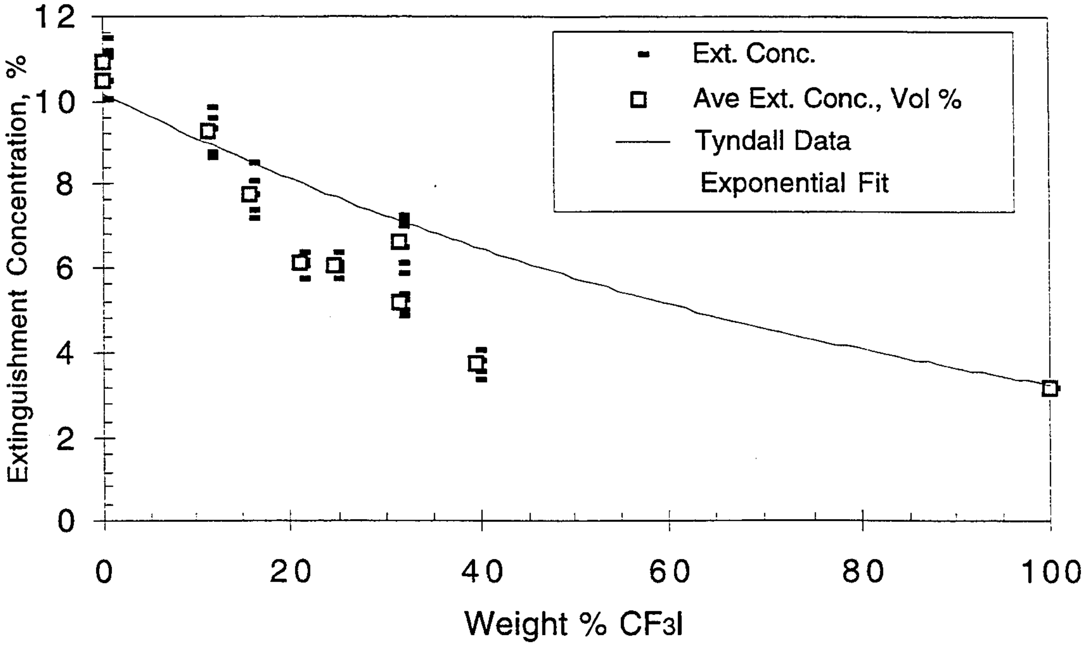

Figure 4. Cup-Burner Extinguishment Concentrations for CF_3I and HFC-134a Blends.

TABLE 10. CUP-BURNER DATA FOR CF_3I AND HFC-125 BLENDS.

Blend HFC-125/CF_3I, %	Test No.	Wt. % CF_3I	Ext. Conc., Vol. %	Ave Ext. Conc., Vol. %	Standard Deviation	% Error
100% HFC-125	NMERI Value	0	9.4	9.4		
100% HFC-125	1	0.0	9.5	9.1	0.3	3.8
	2	0.0	8.8			
	3	0.0	8.7			
	4	0.0	9.2			
	5	0.0	9.3			
88.5/11.5	1	11.5	6.4	6.0	0.6	9.2
	2	11.5	5.9			
	3	11.5	6.3			
	4	11.5	6.5			
	5	11.5	5.1			
82.4/17.6	1	17.6	6.9	7.4	0.3	4.7
	2	17.6	7.5			
	3	17.6	7.3			
	4	17.6	7.8			
	5	17.6	7.3			
80.6/19.4	1	19.4	6.4	6.6	0.2	3.1
	2	19.4	6.4			
	3	19.4	6.7			
	4	19.4	6.9			
	5	19.4	6.7			
75.3/24.7	1	24.7	5.2	5.8	0.5	7.9
	2	24.7	5.8			
	3	24.7	5.9			
	4	24.7	5.5			
	5	24.7	6.4			
69.5/30.5	1	30.5	4.0	3.6	0.4	11.3
	2	30.5	4.0			
	3	30.5	3.6			
	4	30.5	3.1			
	5	30.5	3.2			
60.3/39.7	1	39.7	3.1	3.2	0.3	8.0
	2	39.7	3.4			
	3	39.7	3.5			
	4	39.7	2.9			
	5	39.7	3.4			
100% CF_3I	NMERI Value	100.0	3.2	3.2		

TABLE 11. CUP-BURNER DATA FOR CF_3I AND HFC-134a BLENDS.

Blend HFC-134a/CF_3I, %	Test No.	Wt. % CF_3I	Ext. Conc., Vol. %	Ave Ext. Conc., Vol %	Standard Deviation	% Error
100% HFC-134a	NMERI Value	0	10.5	10.5		
100% HFC-134a	1	0.0	10.0	10.9	0.6	5.7
	2	0.0	11.2			
	3	0.0	11.1			
	4	0.0	11.5			
88.6/11.4	1	11.4	8.6	9.2	0.5	5.8
	2	11.4	8.8			
	3	11.4	9.9			
	4	11.4	9.3			
	5	11.4	9.6			
84.2/15.8	1	15.8	7.2	7.8	0.5	6.7
	2	15.8	7.4			
	3	15.8	7.8			
	4	15.8	8.5			
	5	15.8	8.0			
78.9/21.1	1	21.1	6.1	6.1	0.2	3.6
	2	21.1	6.3			
	3	21.1	6.2			
	4	21.1	6.0			
	5	21.1	5.8			
75.5/24.5	1	24.5	6.1	6.1	0.2	4.1
	2	24.5	5.7			
	3	24.5	6.4			
	4	24.5	6.1			
	5	24.5	5.9			
68.5/31.5	1	31.5	5.0	5.2	0.2	4.3
	2	31.5	4.9			
	3	31.5	5.4			
	4	31.5	5.4			
	5	31.5	5.2			
	6	31.5	5.9	6.6	0.6	8.4
	7	31.5	6.1			

TABLE 11. CUP-BURNER DATA FOR CF_3I AND HFC-134a BLENDS (CONCLUDED).

Blend HFC-134a/CF_3I, %	Test No.	Wt. % CF_3I	Ext. Conc., Vol. %	Ave Ext. Conc., Vol %	Standard Deviation	% Error
	8	31.5	6.5			
	9	31.5	7.0			
	10	31.5	7.1			
	11	31.5	7.2			
60.4/39.6	1	39.6	3.8	3.7	0.3	7.0
	2	39.6	3.8			
	3	39.6	4.0			
	4	39.6	3.4			
	5	39.6	3.5			
100% CF_3I	NMERI Value	100.0	3.2	3.2		

Figure 5 and Table 12 show the cup-burner results for CF_3I blended with HFC-227ea using the revised cup-burner test setup and the classical setup. The one classical test method value that is shown in Figure 5 is much higher than those determined using the revised method. Also, the extinguishment concentrations for the 20 percent through 80 percent CF_3I blends are less than the extinguishment concentration for 100 percent CF_3I. An explanation for this has not been determined at this time.

Figure 6 and Table 13 show the revised cup-burner test results for CF_3I blended with HFC-236fa. An exponential curve fit to the Tyndall ARA data is also shown. The data in Figure 6 show significant scatter, which is not typical of that observed for other compounds tested. This scatter has been attributed to possible composition change as agent was expelled. Also, Tyndall and NMERI results differ. In Figure 7, the average cup-burner results for the CF_3I and HFC-236fa blends are shown, along with the classical method results and an exponential fit to the Tyndall data. The classical test method data and the Tyndall data are in close agreement, as shown by the exponential fit to both the Tyndall and NMERI classical method data (Figure 7); however, the extinguishment concentrations are higher than for the revised method.

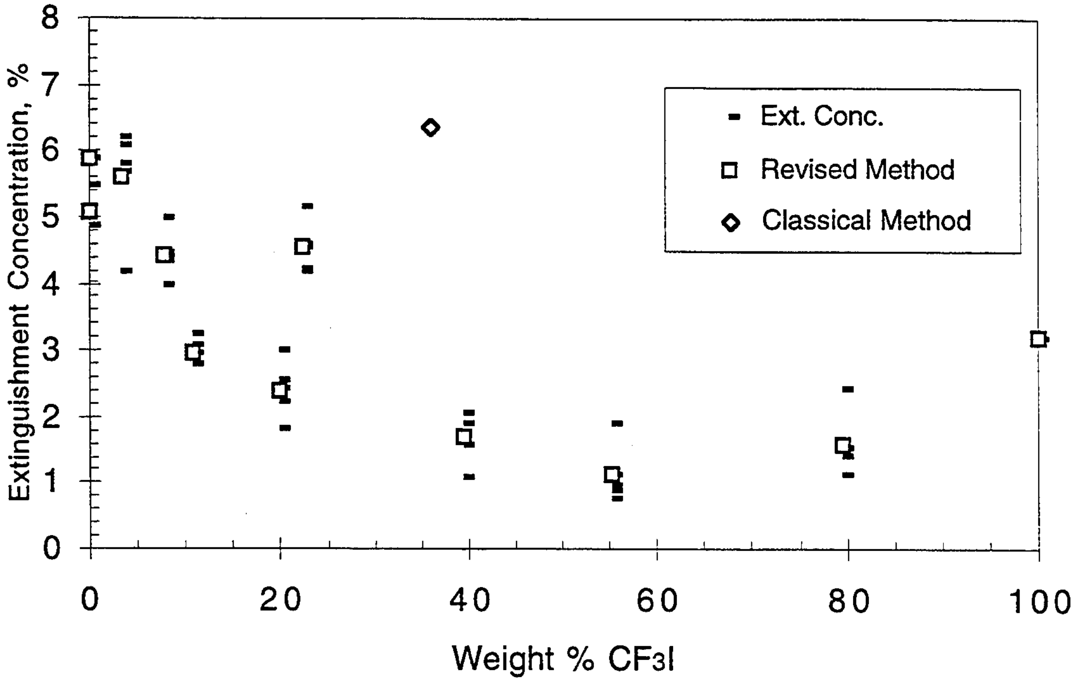

Figure 5. Cup-Burner Extinguishment Concentrations for CF_3I and HFC-227ea Blends.

TABLE 12. CUP-BURNER DATA FOR CF_3I AND HFC-227ea BLENDS.

Blend HFC-227ea/CF_3I, %	Ext. Conc., Vol. %	Avg. Ext. Conc., Vol. %	Average Deviation	% Deviation
100% HFC-227ea	4.9	5.1	0.6	11.7
	4.9			
	5.5			
96.8/3.2	4.2	5.6	0.8	14.7
	5.7			
	6.1			
	6.2			
	5.8			
92.4/7.6	5.0	4.4	0.4	8.4
	4.4			
	4.4			
	4.0			
	4.5			
89.2/10.8	3.1	3.0	0.2	6.6
	2.8			
	3.0			
	2.8			
	3.3			
80.2/19.8	1.8	2.4	0.4	17.5
	2.5			
	3.0			
	2.4			
	2.2			
77.5/22.5	5.1	4.5	0.4	8.6
	4.2			
	4.6			
	4.5			
	4.2			
60.5/39.5	1.9	1.7	0.4	22.2
	1.9			
	2.1			
	1.1			
	1.6			
44.8/55.2	1.9	1.1	0.4	39.4
	0.9			
	0.8			
	1.0			
	1.2			
20.5/79.5	1.4	1.6	0.5	31.4
	2.4			
	1.1			
	1.4			
	1.6			
100% CF_3I	3.2	3.2	---	---

TABLE 13. CUP-BURNER DATA FOR CF_3I AND HFC-236fa BLENDS.

Blend HFC-236fa/CF_3I, %	Ext. Conc., Vol. %	Avg. Ext. Conc., Vol. %	Average Deviation	% Deviation
100% HFC-236fa	5.6	5.6	---	---
97.7/2.3	5.1	4.7	0.5	9.7
	5.1			
	4.5			
	4.7			
	4.0			
95.7/4.3	4.0	4.7	0.4	9.1
	5.2			
	4.4			
	4.4			
	4.7			
	4.9			
	5.1			
93.6/6.4	4.9	5.7	0.6	10.9
	5.7			
	5.3			
	6.4			
	6.5			
	5.5			
93.4/6.6	3.7	3.7	0.4	9.8
	4.1			
	3.5			
	3.2			
	3.9			
	3.2			
	3.9			
91.4/8.6	3.9	3.1	0.7	22.1
	3.3			
	2.9			
	2.1			
	3.2			

TABLE 13. CUP-BURNER DATA FOR CF_3I AND HFC-236fa BLENDS (CONTINUED).

Blend HFC-236fa/CF_3I, %	Ext. Conc., Vol. %	Avg. Ext. Conc., Vol. %	Average Deviation	% Deviation
90.4/9.6	4.5	5.0	1.0	20.9
	4.0			
	3.8			
	5.6			
	5.6			
	6.5			
86.8/13.2	2.6	2.6	0.31	11.9
	3.0			
	2.2			
	2.6			
	2.7			
86.5/13.5	4.1	4.9	0.5	10.1
	4.5			
	4.8			
	5.0			
	5.2			
	5.6			
	5.1			
83.3/16.7	4.9	5.0	0.2	3.8
	5.2			
	4.8			
	5.2			
	4.9			
80/20	3.3	3.3	0.3	9.0
	2.9			
	3.3			
	3.7			
	3.5			
	3.6			
76.9/23.1	3.7	3.9	0.1	3.8
	3.9			
	3.9			
	3.8			
	3.7			
	4.1			

TABLE 13. CUP-BURNER DATA FOR CF_3I AND HFC-236fa BLENDS (CONCLUDED).

Blend HFC-236fa/CF_3I, %	Ext. Conc., Vol. %	Avg. Ext. Conc., Vol. %	Average Deviation	% Deviation
74.2/25.8 (Series 1)	4.3	3.5	0.6	17.7
	3.9			
	3.4			
	2.9			
	2.9			
74.2/25.8 (Series 2)	4.5	6.3	1.4	21.9
	7.2			
	6.2			
	7.6			
68.9/31.1	4.5	4.2	0.2	5.4
	4.1			
	3.9			
	4.2			
	4.4			
	4.2			
58.5/41.5	3.9	3.8	0.2	4.6
	4.0			
	3.8			
	3.5			
	3.7			
56.4/43.5	3.3	3.3	0.4	12.2
	3.8			
	2.8			
	3.4			
100% CF_3I	3.2	3.2	---	----

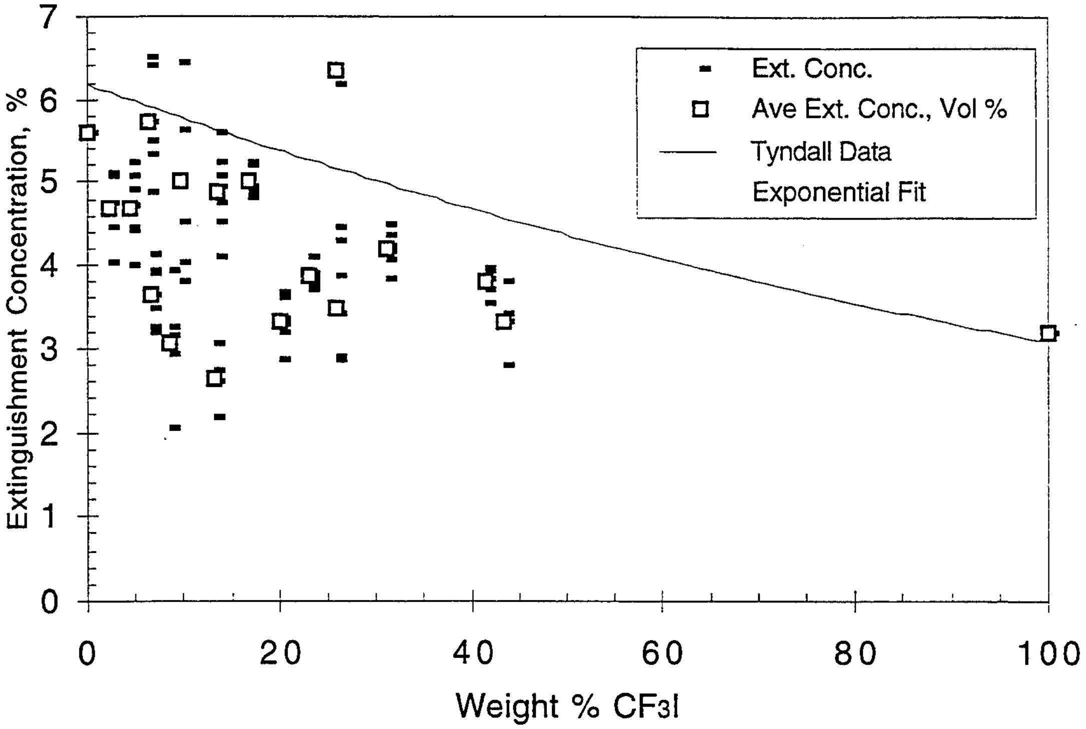

Figure 6. Cup-Burner Extinguishment Concentrations for CF_3I and HFC-236fa Blends.

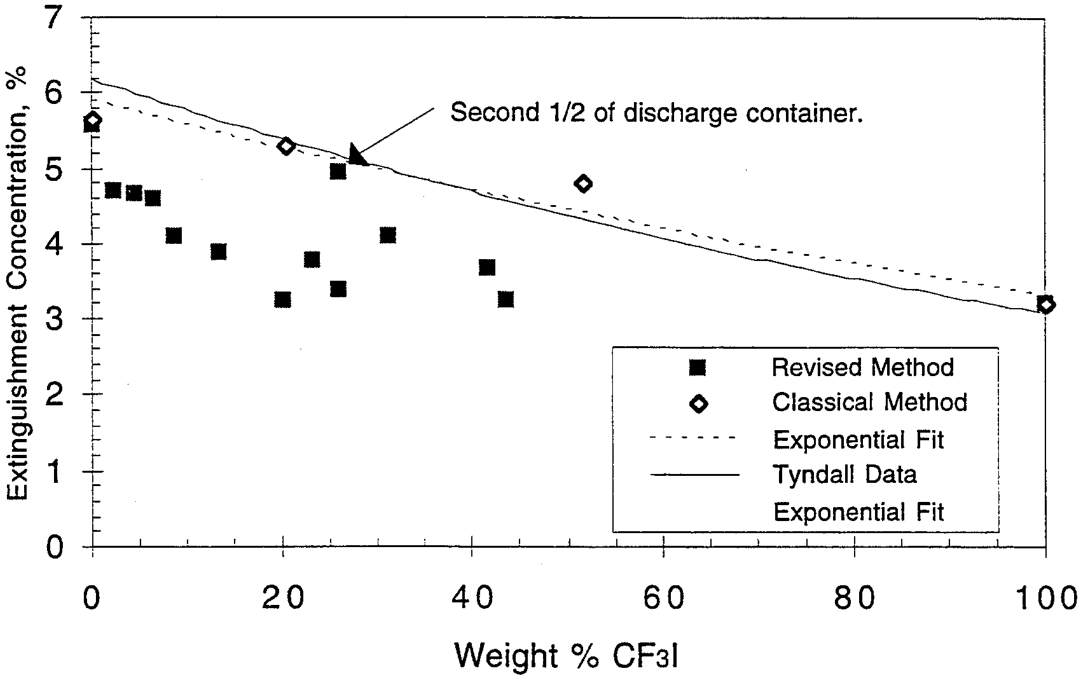

Figure 7. Average Cup-Burner Extinguishment Concentrations for CF_3I and HFC-236fa Blends.

C. DISCUSSION

As shown in Figures 6 and 7 there are differences between the extinguishment concentrations when using the classical and the revised methods as the weight percentage of CF_3I increases. This difference could be due to separation or inadequate mixing of the CF_3I and the HFC compound in the small discharge cylinder (Figure 2). If the denser component, CF_3I, is discharged though the cup burner first, followed by the HFC, it would be expected that the extinguishment concentration of a blend would increase as more and more of the blend is discharged from the cylinder.

Three experiments were performed with the goal of explaining the difference between the extinguishment concentrations when using the two methods. The first experiment entailed investigating the extinguishment concentration values for each cup-burner extinguishment series. In the cup-burner extinguishment series, five tests are performed to determine the average concentration value for the blend. Typically, 100 grams total of the blend were loaded into the discharge cylinder; however, 50 to 70 grams were used during the five tests. If CF_3I is being discharged first, due to its being on the bottom of the discharge cylinder, then the measured extinguishment concentration will increase as more agent is discharged from the cylinder. The first extinguishment test for each blend would have a lower concentration value than the last extinguishment test. The results from the cup-burner testing of the CF_3I blends are shown in Tables 11 - 13. The data presented in these tables do not show any increasing trend, indicating that no separation is taking place (Table 14).

Figure 7 and Table 13 show the results of a second experiment that was performed to investigate the possibility of CF_3I separation. In this experiment, five extinguishment tests were performed with the 25.8 percent CF_3I and 74.2 percent HFC-236fa blend (Table 13). At the end of the first five tests, the discharge cylinder was shaken and another series of five tests was performed. The extinguishing concentration shown in Figure 7 for the second half of the discharge cylinder is higher than the first half of the cylinder, which indicates that separation of CF_3I in the blend could be occurring.

TABLE 14. SELECTED DATA FOR 68.9 PERCENT HFC-236fa AND 31.1 PERCENT CF_3I BLEND.

Test No.	Ext. Conc., Vol %	Weight Used During Test, g
1	4.4	18.0
2	4.0	5.7
3	3.8	6.3
4	4.0	10.3
5	4.2	13.1
6	4.1	12.0
	Average = 4.1	Total = 65.4

[a] Initial blend weight in cylinder was 144 g total with 44.7 g CF_3I.

[b] The total weight discharged exceeded the amount of CF_3I in the blend.

A third experiment was performed. In this experiment, a Fourier Transform Infrared (FTIR) spectrometer was used to observe the CF_3I and HFC-236fa peaks throughout a series of cup-burner tests. In the FTIR experiment, the cup-burner discharge cylinder was filled with the CF_3I and HFC blend and the standard cup-burner extinguishment experiment was performed. Just prior to and right after the agent blend extinguished the cup-burner flame, several scans were taken with the FTIR. The peak heights and ratios between the CF_3I and HFC peaks are shown in Tables 15 and 16. Six example FTIR spectra are shown in Figures 8 - 13. The ratios between the CF_3I and HFC-227ea peaks in Table 15 indicate that the composition of the blended agents in the blend remained the same throughout the discharge, indicating that separation of CF_3I was not occurring. The same appears to be true for Blend Tests 4, 5, 6, 7, 8, and 10 for HFC-236fa (Table 16). Slight differences did occur between the ratios of the second peaks on Table 16; however, as shown in Figures 10 - 13, the second CF_3I peak is slightly influenced by a HFC-236fa peak. Additional investigations of this phenomena are ongoing.

TABLE 15. FTIR EXPERIMENTAL TEST RESULTS: CF_3I AND HFC-227ea BLENDS.

Name	CF_3I	HFC-227ea	HFC-227ea	Ratio of CF_3I to HFC-227ea	
	Peak 1	Peak 1	Peak 2	Peak 1	Peak 2
BLEND TEST #1: 21.2% CF_3I and 78.8% HFC-227ea					
BLEND1B.SP	0.100	0.187	0.123	0.53	0.81
BLEND1C.SP	0.182	0.335	0.220	0.54	0.83
BLEND1D.SP	0.010	0.021	0.015	0.48	0.67
BLEND1E.SP	0.014	0.025	0.019	0.56	0.74
BLEND1F.SP	0.224	0.415	0.274	0.54	0.82
BLEND1G.SP	0.202	0.377	0.249	0.54	0.81
BLEND1H.SP	0.013	0.023	0.016	0.57	0.81
BLEND1I.SP	0.146	0.276	0.183	0.53	0.80
BLEND1J.SP	0.011	0.022	0.016	0.50	0.69
BLEND1K.SP	0.092	0.180	0.118	0.51	0.78
BLEND1L.SP	0.236	0.435	0.287	0.54	0.82
BLEND1M.SP	0.009	0.018	0.013	0.50	0.69
BLEND1N.SP	0.095	0.166	0.110	0.57	0.86
BLEND1O.SP	0.163	0.300	0.198	0.54	0.82
BLEND1P.SP	0.181	0.333	0.222	0.54	0.82
BLEND TEST #2: 23.1% CF_3I and 76.9% HFC-227ea					
BLEND2A.SP	0.073	0.122	0.079	0.60	0.92
BLEND2B.SP	0.155	0.259	0.170	0.60	0.91
BLEND2C.SP	0.257	0.460	0.301	0.56	0.85
BLEND2D.SP	0.213	0.385	0.255	0.55	0.84
BLEND2E.SP	0.233	0.408	0.268	0.57	0.87
BLEND2F.SP	0.206	0.372	0.247	0.55	0.83
BLEND2H.SP	0.099	0.169	0.107	0.59	0.93
BLEND2K.SP	0.168	0.295	0.193	0.57	0.87
BLEND2L.SP	0.188	0.333	0.218	0.56	0.86
BLEND2M.SP	0.557	0.934	0.624	0.60	0.89
BLEND2N.SP	1.218	2.661	1.463	0.46	0.83

TABLE 16. FTIR EXPERIMENTAL TEST RESULTS: CF_3I AND HFC-236fa BLENDS.

Name	CF_3I Peaks		HFC-236fa Peaks		Ratio of CF_3I to HFC-236fa			
	1a	2a	1b	2b	1a/1b	1a/2b	2a/1b	2a/2b
BLEND4A.SP	0.046	0.033	0.166	0.180	0.28	0.26	0.20	0.18
BLEND4B.SP	0.031	0.024	0.102	0.115	0.30	0.27	0.24	0.21
BLEND4C.SP	0.029	0.024	0.098	0.105	0.30	0.28	0.24	0.23
BLEND4D.SP	0.029	0.025	0.100	0.109	0.29	0.27	0.25	0.23
BLEND4E.SP	0.036	0.022	0.069	0.081	0.52	0.44	0.32	0.27
BLEND4F.SP	0.033	0.029	0.123	0.135	0.27	0.24	0.24	0.21
BLEND4G.SP	0.031	0.022	0.064	0.093	0.48	0.33	0.34	0.24
BLEND4H.SP	0.031	0.022	0.064	0.134	0.48	0.23	0.34	0.16
				Average =	0.37	0.29	0.27	0.22
				Std. Dev. =	0.11	0.07	0.06	0.03
BLEND5A.SP	0.035	1.314	0.128	0.347	0.27	0.10	10.27	3.79
BLEND5B.SP	0.043	1.031	0.104	0.344	0.41	0.13	9.91	3.00
BLEND5C.SP	0.077	0.904	0.358	0.473	0.22	0.16	2.53	1.91
BLEND5D.SP	0.039	0.674	0.182	0.268	0.21	0.15	3.70	2.51
BLEND5E.SP	0.087	0.630	0.344	0.392	0.25	0.22	1.83	1.61
BLEND5F.SP	0.074	0.585	0.286	0.330	0.26	0.22	2.05	1.77
BLEND5G.SP	0.115	0.539	0.428	0.478	0.27	0.24	1.26	1.13
BLEND5H.SP	0.032	0.402	0.154	0.266	0.21	0.12	2.61	1.51
				Average =	0.26	0.17	4.27	2.15
				Std. Dev. =	0.07	0.05	3.66	0.88
BLEND6A.SP	0.027	0.434	0.129	0.355	0.21	0.08	3.36	1.22
BLEND6B.SP	0.025	0.387	0.060	0.293	0.42	0.09	6.45	1.32
BLEND6C.SP	0.085	0.451	0.319	0.447	0.27	0.19	1.41	1.01
BLEND6D.SP	0.045	0.425	0.158	0.182	0.28	0.25	2.69	2.34
BLEND6E.SP	0.061	0.441	0.208	0.238	0.29	0.26	2.12	1.85
BLEND6F.SP	0.044	0.427	0.153	0.178	0.29	0.25	2.79	2.40
BLEND6G.SP	0.100	0.473	0.324	0.362	0.31	0.28	1.46	1.31
BLEND6H.SP	0.141	0.498	0.450	0.509	0.31	0.28	1.11	0.98
				Average =	0.30	0.21	2.67	1.55
				Std. Dev. =	0.06	0.08	1.71	0.57

TABLE 16. FTIR EXPERIMENTAL TEST RESULTS: CF_3I AND HFC-236fa BLENDS (CONTINUED).

Name	CF_3I Peaks		HFC-236fa Peaks		Ratio of CF_3I to HFC-236fa			
	1a	2a	1b	2b	1a/1b	1a/2b	2a/1b	2a/2b
BLEND7A.SP	0.002	0.176	0.008	0.101	0.25	0.02	22.00	1.74
BLEND7B.SP	0.150	0.290	0.494	0.651	0.30	0.23	0.59	0.45
BLEND7C.SP	0.129	0.280	0.431	0.500	0.30	0.26	0.65	0.56
BLEND7D.SP	0.063	0.220	0.198	0.234	0.32	0.27	1.11	0.94
BLEND7E.SP	0.131	0.254	0.425	0.492	0.31	0.27	0.60	0.52
BLEND7F.SP	0.051	0.192	0.178	0.208	0.29	0.25	1.08	0.92
BLEND7G.SP	0.230	0.305	0.742	0.829	0.31	0.28	0.41	0.37
BLEND7H.SP	0.127	0.225	0.399	0.462	0.32	0.27	0.56	0.49
				Average =	0.30	0.23	3.37	0.75
				Std. Dev. =	0.02	0.09	7.53	0.46
BLEND8A.SP	0.399	0.931	0.700	---	0.57	---	1.33	---
BLEND8B.SP	0.162	0.318	0.256	---	0.63	---	1.24	---
BLEND8C.SP	0.127	0.230	0.198	---	0.64	---	1.16	---
BLEND8D.SP	0.239	0.288	0.370	---	0.65	---	0.78	---
BLEND8E.SP	0.155	0.172	0.246	---	0.63	---	0.70	---
BLEND8F.SP	0.109	0.126	0.174	---	0.63	---	0.72	---
BLEND8G.SP	0.081	0.105	0.134	---	0.60	---	0.78	---
BLEND8H.SP	0.064	0.098	0.114	---	0.56	---	0.86	---
				Average =	0.61	---	0.95	---
				Std. Dev. =	0.03	---	0.25	---
BLEND9A.SP	0.063	0.662	0.248	---	0.25	---	2.67	---
BLEND9B.SP	0.131	0.686	0.352	---	0.37	---	1.95	---
BLEND9C.SP	0.233	0.725	0.445	---	0.52	---	1.63	---
BLEND9D.SP	0.228	0.680	0.418	---	0.55	---	1.63	---
BLEND9E.SP	0.098	0.219	0.187	---	0.52	---	1.17	---
BLEND9F.SP	0.237	0.290	0.419	---	0.57	---	0.69	---
BLEND9G.SP	0.146	0.220	0.276	---	0.53	---	0.80	---
BLEND9H.SP	0.113	0.197	0.220	---	0.51	---	0.90	---
				Average =	0.48	---	1.43	---
				Std. Dev. =	0.11	---	0.67	---

TABLE 16. FTIR EXPERIMENTAL TEST RESULTS: CF_3I AND HFC-236fa BLENDS (CONCLUDED).

Name	CF_3I Peaks		HFC-236fa Peaks		Ratio of CF_3I to HFC-236fa			
	1a	2a	1b	2b	1a/1b	1a/2b	2a/1b	2a/2b
BLEND10A.SP	0.344	1.137	0.567	0.691	0.61	0.50	2.01	1.65
BLEND10B.SP	0.275	0.488	0.453	0.544	0.61	0.51	1.08	0.90
BLEND10C.SP	0.199	0.360	0.333	0.400	0.60	0.50	1.08	0.90
BLEND10D.SP	0.175	0.344	0.277	0.318	0.63	0.55	1.24	1.08
BLEND10E.SP	0.155	0.280	0.250	0.297	0.62	0.52	1.12	0.94
BLEND10F.SP	0.133	0.233	0.219	0.274	0.61	0.49	1.06	0.85
BLEND10G.SP	0.314	0.306	0.499	0.577	0.63	0.54	0.61	0.53
BLEND10H.SP	0.215	0.222	0.363	0.432	0.59	0.50	0.61	0.51
				Average =	0.61	0.51	1.10	0.92
				Std. Dev. =	0.01	0.02	0.43	0.35

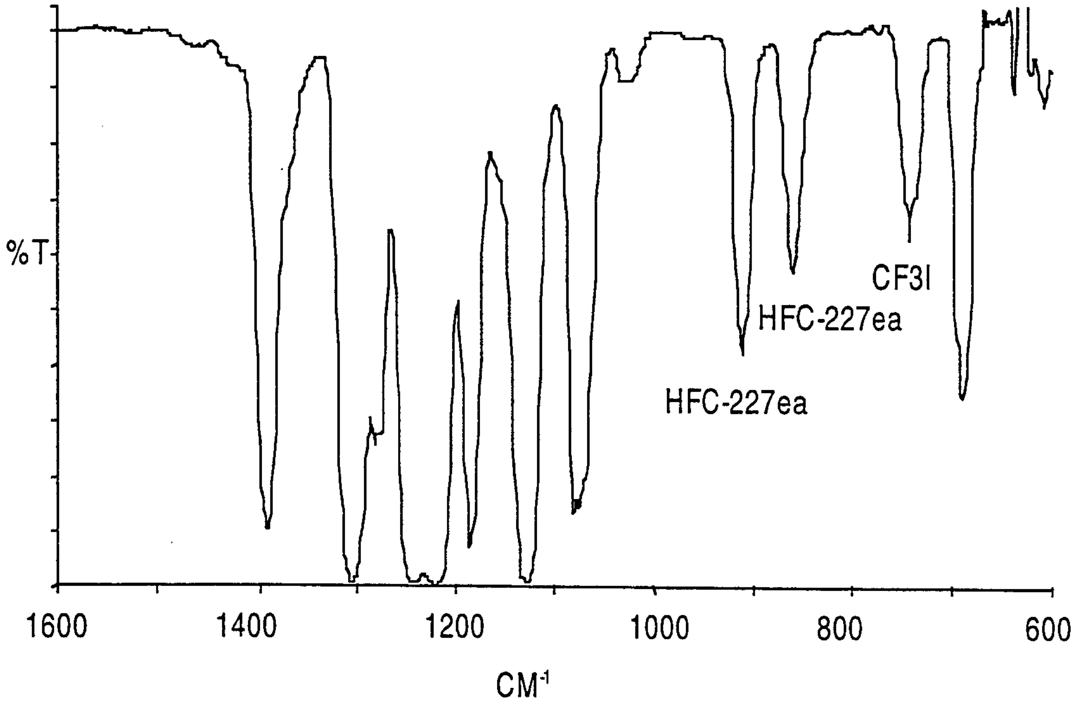

Figure 8. Blend Test #1: 21.2% CF_3I and 78.8% HFC-227ea Scan at Start of Test.

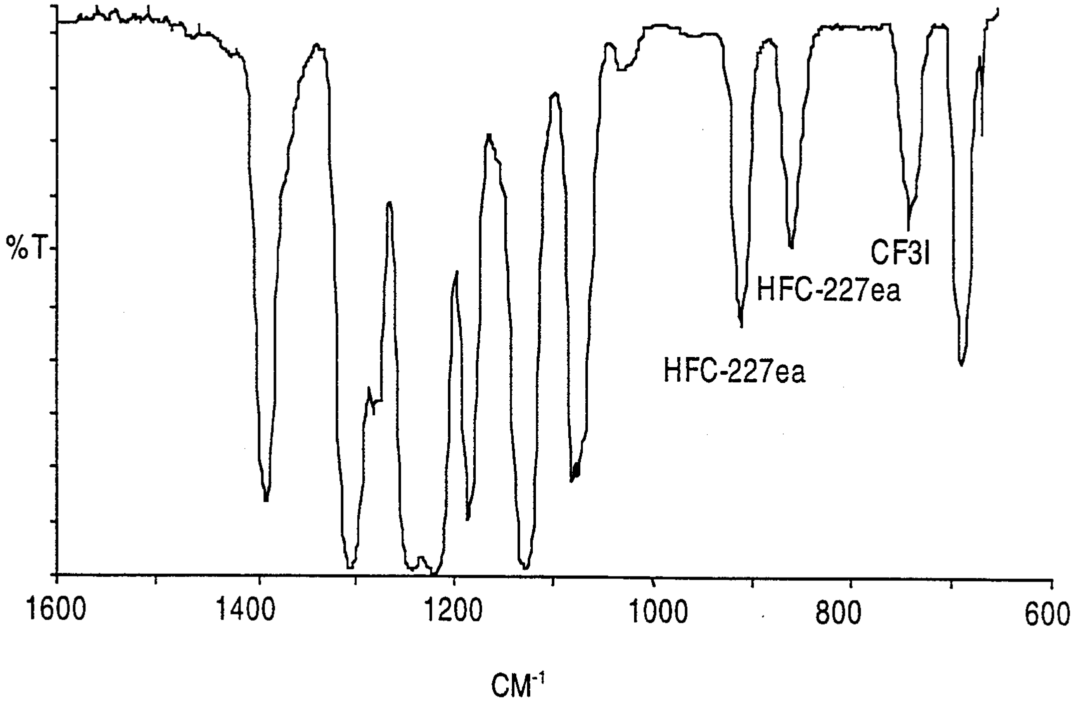

Figure 9. Blend Test #1: 21.2% CF_3I and 78.8% HFC-227ea Scan Toward End of Test.

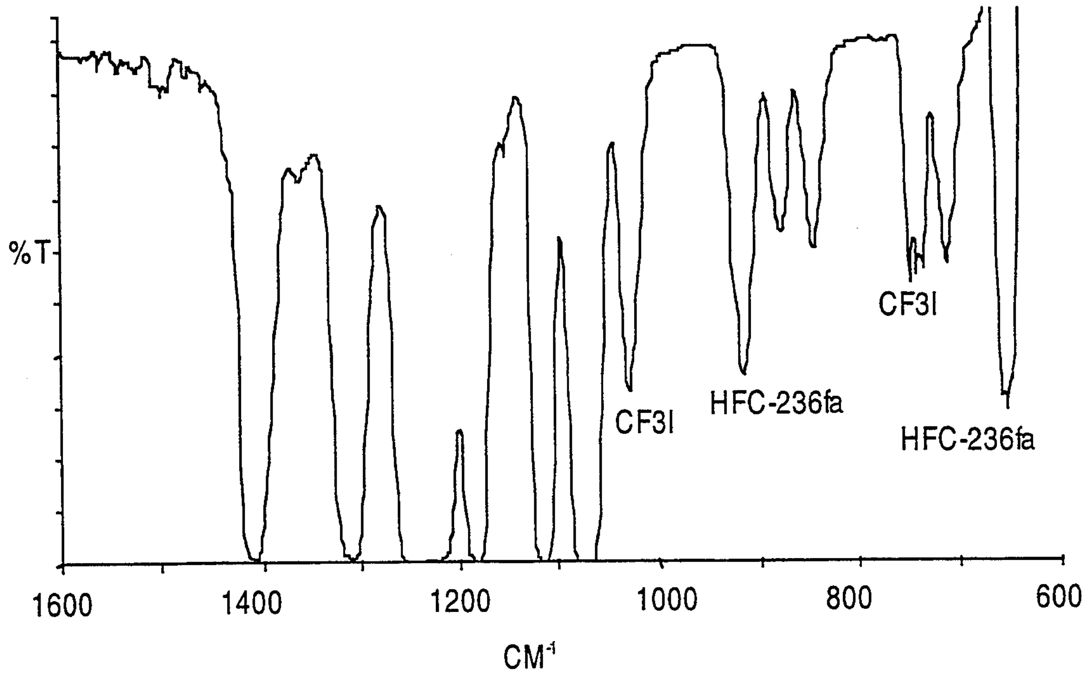

Figure 10. Blend Test #2: 23.1% CF_3I and 76.9% HFC-236fa Scan at Start of Test.

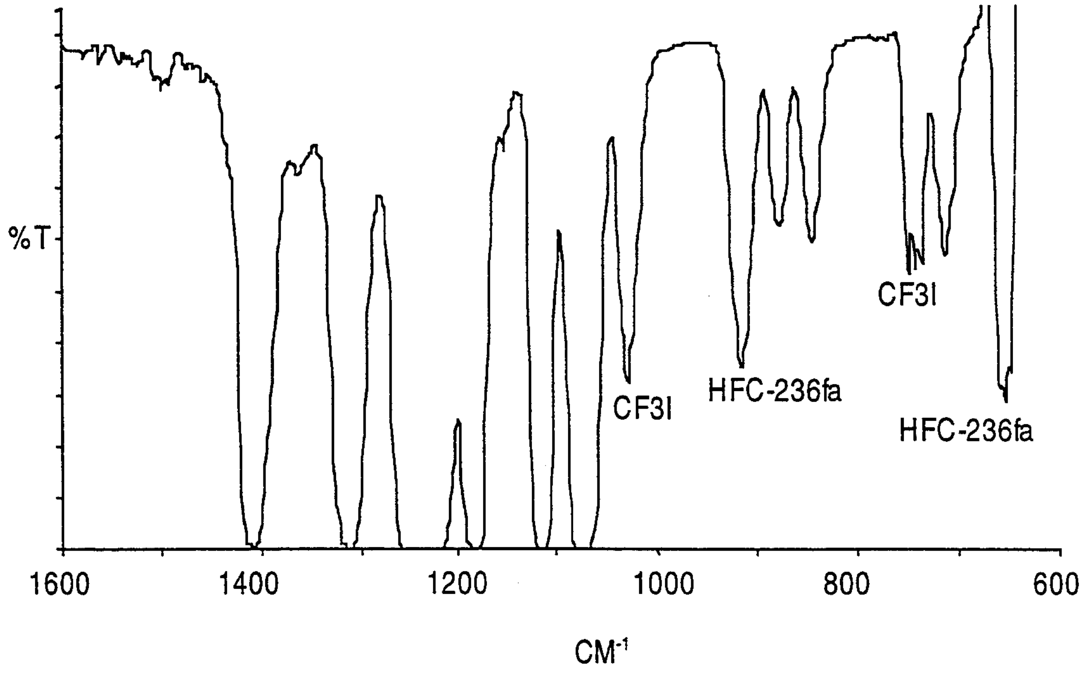

Figure 11. Blend Test #2: 23.1% CF_3I and 76.9% HFC-236fa Scan Toward End of Test.

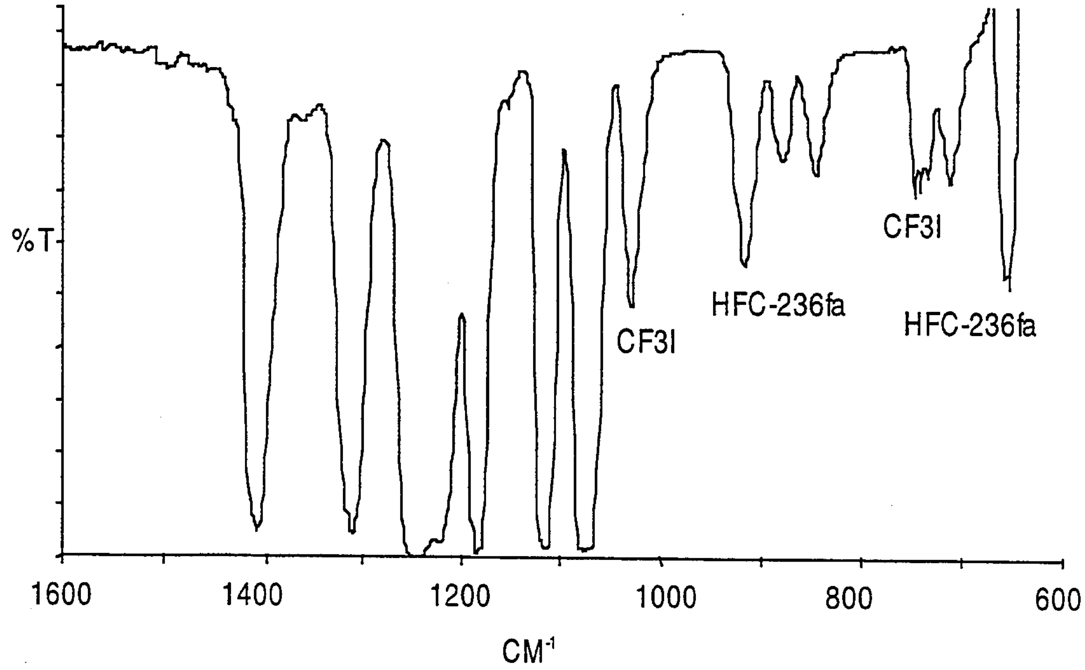

Figure 12. Blend Test #5: 41.5% CF_3I and 58.5% HFC-236fa Scan at Start of Test.

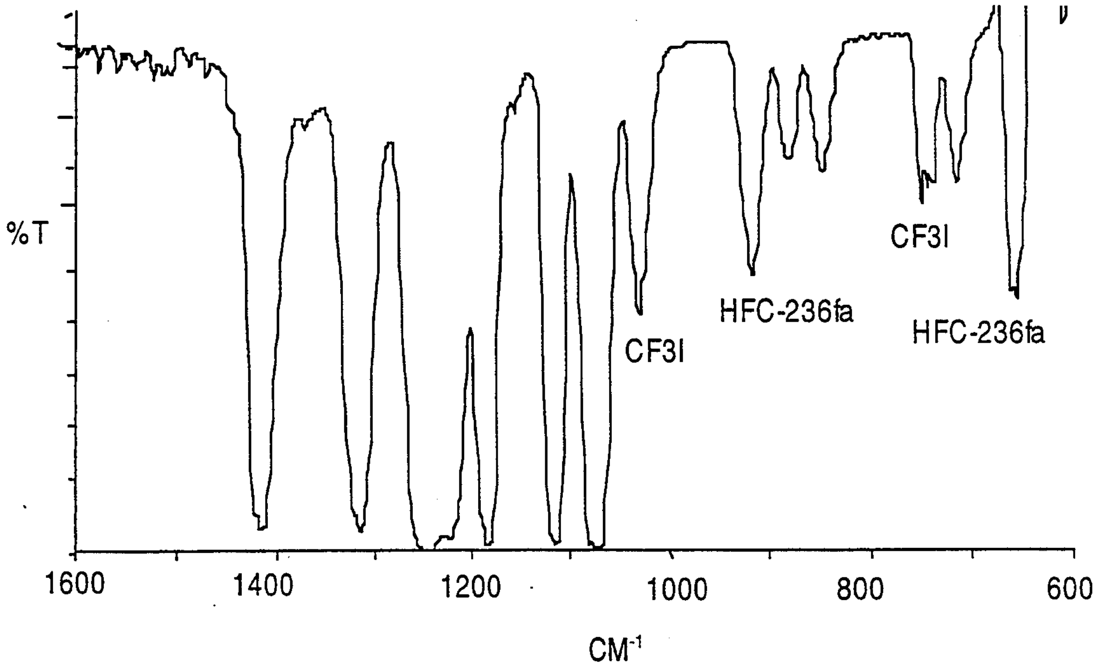

Figure 13. Blend Test #5: 41.5% CF_3I and 58.5% HFC-236fa Scan Toward End of Test.

D. SUMMARY

Figure 14 shows a summary of the CF_3I and HFC blend cup-burner extinguishment concentrations. The Tyndall ARA data are also shown. The CF_3I and HFC-227ea and -236fa blends, as shown, proved to be the most effective of the HFCs tested. The revised cup-burner method results indicate that a 20 to 40 percent by weight blend of CF_3I and HFC-236fa would have a slight decrease in extinguishing performance versus 100 percent CF_3I. Based on the cup-burner test results, it is recommended that laboratory and medium scale testing of CF_3I blends with HFC-227ea and HFC-236fa be performed. Limited testing with either HFC-134a or HFC-125 may also be warranted. These agents, however, have low boiling points and are likely to be inadequate as streaming agents.

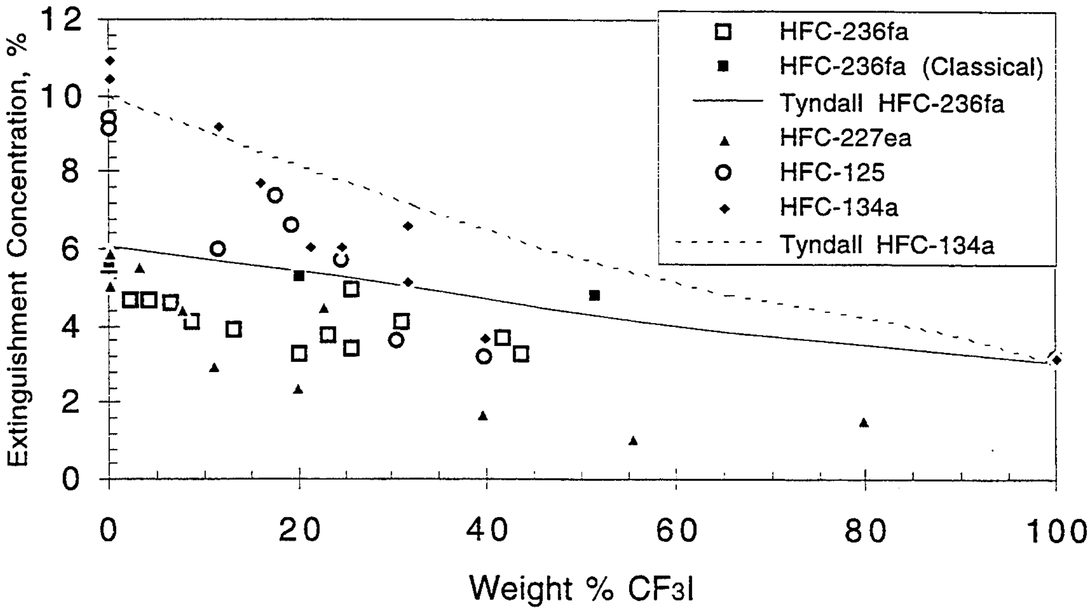

Figure 14. Summary of Cup-Burner Extinguishment Concentrations for HFC and CF_3I Blends.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Seven HFC agents (HFC-23, -125, -134a, -143a, -227ea, -236fa, and -4-3-10mee) have been identified that meet toxicity, regulatory, and availability requirements for inclusion as blending agents with CF_3I. For five of the compounds that are widely available and have known cardiac sensitization NOAEL values, no more than 40 percent CF_3I may be contained in a blend in order to match the cardiac sensitization NOAEL value of Halon 1211. Fire suppression effectiveness testing using the cup-burner method indicates that the extinguishing concentrations of four 40 percent blends range from slightly higher than that of CF_3I to significantly lower. Analysis of FTIR scans at different times shows no fractionation of agents during discharge. CF_3I blends with HFC-227ea and HFC-236fa are the most likely to meet USAF streaming agent requirements.

B. RECOMMENDATIONS

Those agents identified as meeting the criteria for continuation in the program should be tested in laboratory- and field-scale streaming apparatuses. Toxicity assessments of one or more blends identified in this program should be conducted.

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FLUOROIODIDE BLENDS AS STREAMING AGENTS: SELECTION CRITERIA AND CUP-BURNER RESULTS

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